TECHNICAL REPORT

ASWEPS REPORT NO. 7

SEA SURFACE TEMPERATURE SYNOPTIC ANALYSIS

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ABSTRACT

A technique is described for preparing detailed sea surface temperature analyses for large ocean areas. These analyses utilize injection temperature observations taken by commercial ships. The inadequacies of analyses based on averaged data and some difficulties inherent in contouring scalar fields are discussed.

Sea surface temperatures are interpreted according to some concepts derived from cross-sectional profiles and surface current data. Isotach analyses of mean current drift are considered as flow patterns to aid temperature analysis in areas where data are sparse.

FOREWORD

A practical presentation of the daily sea surface temperature field in the form of contoured charts is of wide general utility and has specific applications in naval operations, as well as commercial enterprises. In particular, knowledge of the sea surface temperature at a given locality is used in the AntiSubmarine Warfare Environmental Prediction System (ASWEPS) being developed by the Hydrographic Office

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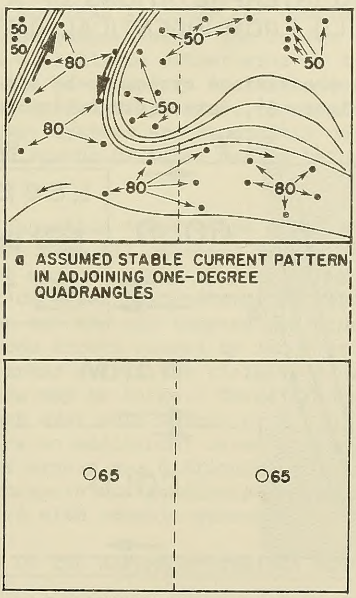
Hydrographer

CONTENTS

I. INTRODUCTION

In connection with the development of an oceanographic prediction system (ASWEPS), the Hydrographic Office is currently preparing experimental sea surface temperature charts. These charts cover a small area of the western North Atlantic and are prepared for periods of 1, 10, and 30 days. Sea surface temperature analytic techniques and theory are discussed in the following sections.

The isotherms of long-term mean sea surface temperature charts are generally west-east oriented with values increasing toward lower latitudes. In these respects, they resemble mean isobaric patterns derived from large-scale migratory atmospheric systems. Moreover, apparent agreement between orientation of mean isobars and resultant ocean current drift suggests that water temperatures may be related to wind-driven currents. Since the patterns of mean charts depend only on resultant values averaged over specified unit areas, they do not necessarily represent the true nature of a given field. This would be especially true if the systems comprising a particular field were narrow, elongated bands separated by sharp gradient zones (Figure 1a), and the dimensions of the unit areas on which mean charts are based were relatively large when compared to the width of the systems (Figure 1b).



b MEAN TEMPERATURES DEDUCED FROM DATA IN THE ABOVE QUADRANGLES

FIGURE 1 POSSIBLE MISREPRESENTATION OF A STABLE TEMPERATURE FIELD BY MEAN CHARTS

Consecutive daily sea surface temperature charts show frequent abrupt changes in their isotherm patterns. Experience indicates that the majority of such changes arise from data errors, data distribution, and the analyst's concepts of temperature variation in the sea. Indeed, identical data on successive charts can be variously interpreted (Figure 2).

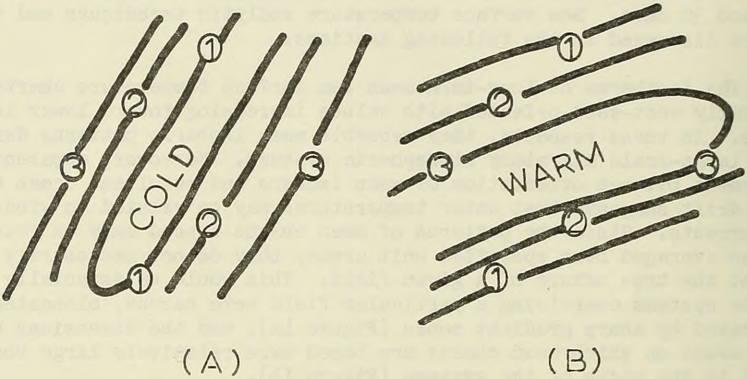


FIGURE 2 TWO INTERPRETATIONS OF A TEMPERATURE FIELD FROM INDENTICAL DATA

If one assumes the surface system to be alternate parallel warm and cold water bands (Figure 3), data distribution on successive charts may

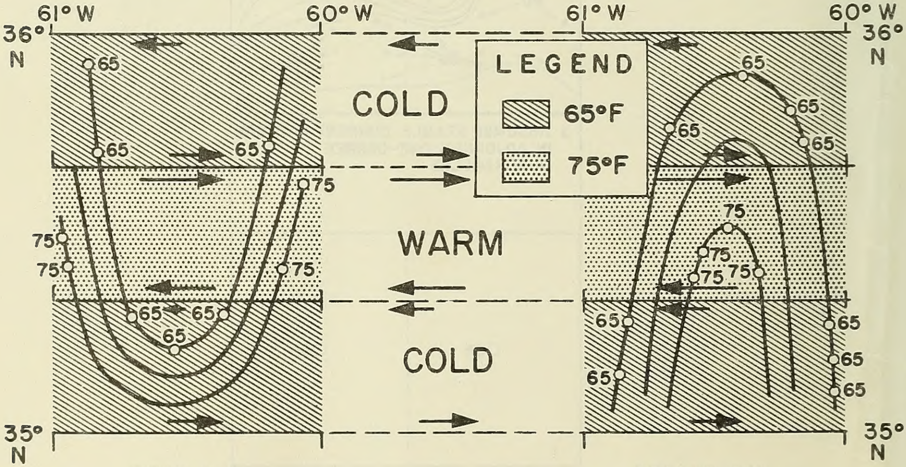


FIGURE 3 SURFACE TEMPERATURE (WAVE) PATTERNS DEDUCED FROM DIFFERENT DATA DISTRIBUTION IN ALTERNATE PARALLEL CURRENTS IN THE SAME AREA ON SUCCESSIVE DAYS

give rise to an erroneous temperature wave, the period of which would be dependent on the chart interval. If the plotted values in Figure 3 had actually resulted from a meandering current, they could just as well be interpreted as having arisen from straight currents.

II. DATA EVALUATION

Quasi-synoptic sea surface temperature charts for extensive ocean areas are of necessity based on injection temperature observations reported at 6-hour intervals to various meteorological organizations by commercial ships.

Injection intake depths normally range between 20 and 25 feet, whereas bucket readings are taken near the air-water boundary. Assuming the thermometers are accurate, injection readings will be relatively low when the vertical temperature gradient is negative, relatively high when the gradient is positive, and equal to bucket readings when the water is uniformly mixed.

Choice of temperature recording instruments obviously must be compatible with planned use of the data. The depth of the heated layer in cold currents varies from zero to roughly 200 feet, depending on latitude and season. Therefore, again assuming the thermometers are accurate, bucket temperatures are less suitable for outlining ocean currents during summer than injection temperatures; the latter fail completely between 15 and 20 degrees of latitude either side of the Equator. Temperatures recorded by bucket thermometers in the heated layers of cold currents at low latitudes may slightly exceed those of warm currents. At low latitudes the current systems are apparently well outlined by isotach analyses - surface speeds of water masses being transmitted from below the heated layer.

About 20 percent of injection temperature data is estimated to contain gross and minor errors from all causes. Sample checks of ship weather logs indicate that approximately 13 percent of these errors arises through processing of water temperatures for transmission in terms of surface air temperature and the air temperature minus sea temperature difference factor, D. Gross errors caused by incorrect difference factor signs occur near coastal areas and in the vicinity of warm and cold current systems where D values may be large. These errors result in water temperatures 2 x D too high over cold waters or 2 x D too low over warm waters; therefore, they are an additional cause of abrupt changes in isotherm patterns. Such data errors are difficult to detect with certainty, because sharp horizontal temperature gradients (possibly as much as 8° F per mile) can be associated with oceanic currents.

III. SOME CONSIDERATIONS OF THE NATURE OF THE SEA SURFACE

Analyses of weather charts are facilitated by employing wind vectors to show isobaric spacing and orientation. Conversely, both salinity and

current information are seldom available to aid construction of sea temperature charts. Experience indicates, however, that meaningful charts can be realized by employing injection temperatures according to a prescribed technique.

As will be presently more evident, a number of important current systems with numerous tongues are present in the sea along boundary zones of waters of different origin. Because of the limited width and complex configuration of these tongues, the waters associated with oceanic currents are more difficult to delineate than large-scale systems encountered in weather analyses.

Figure 4 presents a vertical temperature cross section and surface current data along the 50th meridian. These data and sections for other ocean areas (not shown) form the bases for the analytical approach described below. Symmetrical undulation of the isotherms indicates four major water masses.

Upon crossing each mass the surface current changes direction in an orderly manner; that is, the circulation is cyclonic for cold waters and anticyclonic for warm waters. There is also general agreement between the magnitudes of temperature gradients and current velocity. If $\bar{V}$ is the surface current velocity, $\bar{K}$ a vertical vector, positive outwards, and ∇T is grad T, the relation $\bar{V} = \bar{K}$ cross ∇T holds in principle. This relation, analogous to that which applies for straight air flow, suggests that water bands can be treated as greatly elongated air masses.

Vertical symmetry manifested by the isotherms in Figure 4 is typical of temperature cross sections taken over wide areas of the North Atlantic Ocean, and indicates that wave action and meteorological conditions do not disturb deep current systems which regulate distribution of temperature and related physical properties in the sea.

Temperature structure (including surface temperature) at any given time in the upper layers apparently depends on the origin and history of the masses as indicated by the two northernmost water masses (Figure 4) which lie in practically the same climatic environment.

The forces expected to be present at various points in interdependent warm and cold current systems are schematically shown in Figure 5, along with an appropriate velocity profile which is placed on the sea surface for convenience. If air masses were substituted for water bands in this figure, a similar velocity profile would be expected. Elongation of the body of uniform warm water can be attributed to frictional drag due to high velocities in the northern transition zone. Under these conditions, the potential width of the uniform water, determined by frictional drag from the stronger transition zone, would decrease with increasing slope along the opposite boundary of the warm water.

Warm waters flowing zonally in the tropics are subjected to long periods of maximum insolation. This results in mixed-layer characteristics which tend to be conserved by convective mixing at higher latitudes. Cold waters from higher latitudes, however, undergo short-term

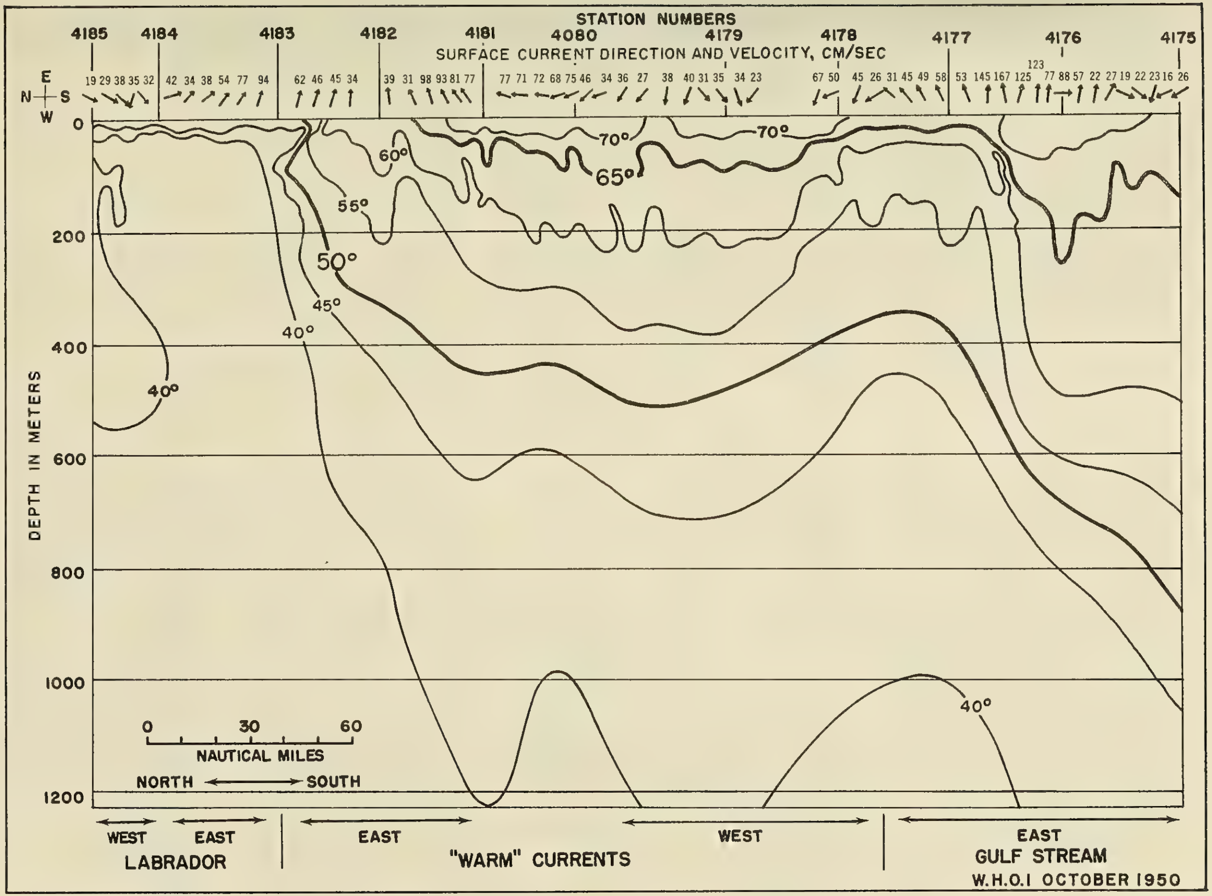


FIGURE 4 TEMPERATURE (°F) PROFILE ALONG THE 50th MERIDIAN SOUTH OF THE GRAND BANKS

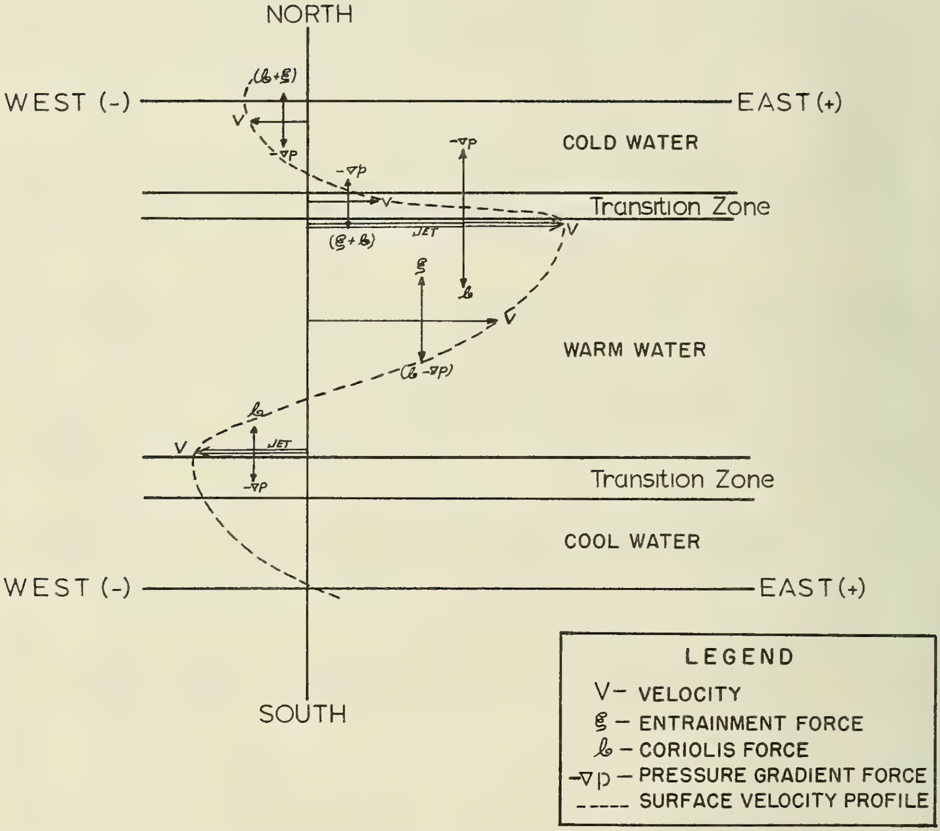


FIGURE 5 SCHEMATIC DIAGRAM INDICATING BALANCED FLOW THROUGH THE GULF STREAM AND ADJACENT WATERS

(seasonal) periods of warming and cooling near the surface and tend to reach extremes in their mixed-layer structure. Cold waters at low latitudes tend to lose their identity because of surface heating. During all seasons, however, the surface positions of warm and cold currents in the North Atlantic are ordinarily discernable from injection temperatures. Because strong negative vertical temperature gradients exist in cold waters during the warm season, upwelling does not satisfactorily explain the continued presence of relatively cold surface water in the open ocean. It appears rather that relatively cool waters mark the surface position of cold currents where advection occurs below the heated layer.

IV. ISOTACH PATTERNS OF MEAN CURRENTS AND THEIR APPLICATION TO TEMPERATURE ANALYSES

In areas where data are sparse or unevenly distributed or in unfamiliar areas where flow patterns are unknown, surface temperatures covering extended periods should be compared with mean isotach patterns. This procedure is especially helpful where currents are apparently constrained by topography; for example, in inland seas and near coastal areas. Studies indicate that high temperatures are related to high isotach values and deep water. An isotach analysis for the Caribbean Sea and the Gulf of Mexico is shown in Figure 6. Isotach configurations were employed as warm and cold flow patterns for interpretation of the temperatures on the composite chart (Figure 7). A series of temperature charts based on the configurations in Figure 6 show only minor pattern changes over a period of several months. Figure 7 indicates an overall surface temperature range of about 9° F even in these latitudes; temperature contrasts between adjacent waters are expected to be appreciably greater below the depth of wave mixing.

Although significant details of the circulation are lost by averaging temperatures and drift values over one-degree quadrangles, Figure 8, in which February drift values (1935-45) are compared with mean isotherms for February 1961, shows that low temperatures correspond to minimum drift and vice versa. Of particular interest is evidence of counter currents south of the 32nd parallel. In connection with the temperature profile and currents off the California coast (Figure 9), it will be noted that, except at the extreme western end of the section where the warm axis is slightly displaced to the right of a marked salinity minimum, currents change direction near the maximal and minimal portions of the trace in agreement with the relation discussed on page 4.

Since mean drift values are ordinarily computed for one-degree quadrangles over long time intervals, only the more gross and permanent features of the circulation are indicated by them. This may be especially true in the deep ocean where current systems are not topographically constrained. Effectiveness of isotach analyses should be greatly enhanced when data density permits averaging of drift values over much smaller unit areas than the present one-degree quadrangle. For example, computations of mean drift for a portion of a permanent warm tongue (Figure 1a) are low, because drift values, although high along its boundary, are oppositely directed.

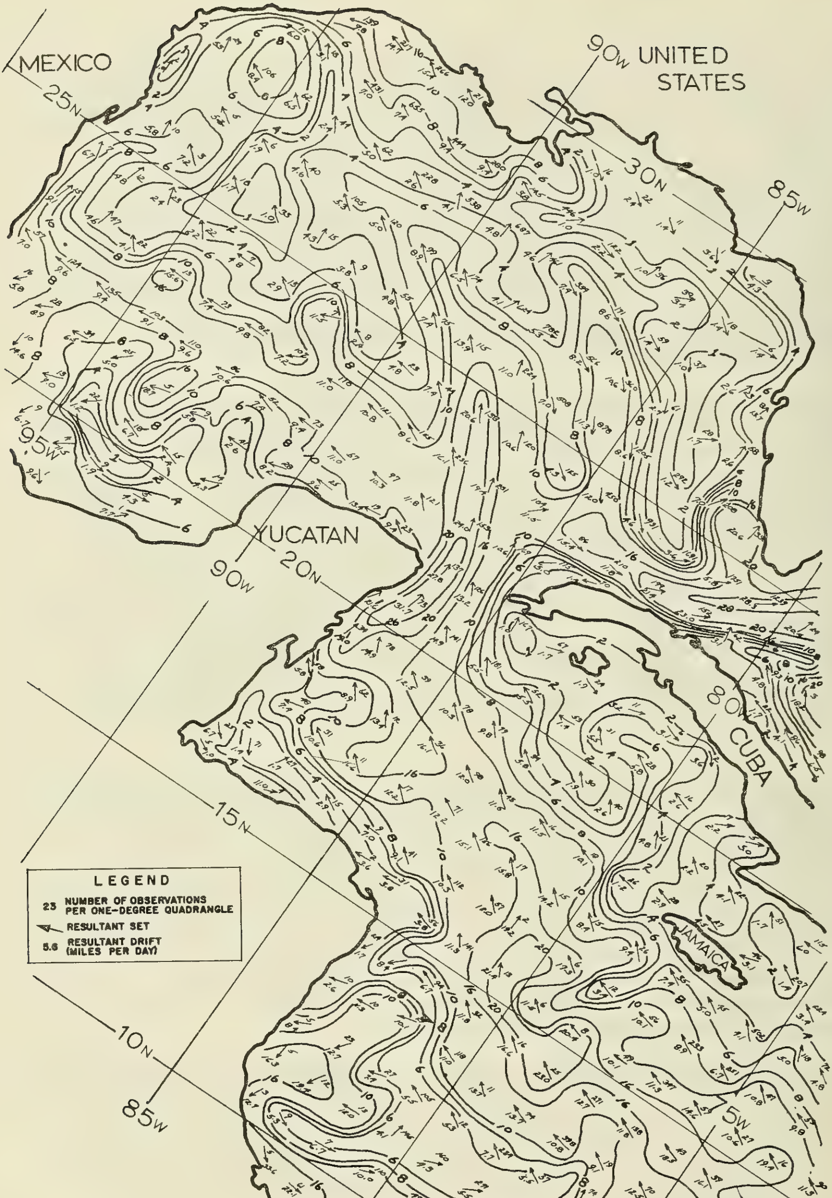


FIGURE 6 ISOTACHS FOR THE CARIBBEAN SEA AND GULF OF MEXICO (OCTOBER)

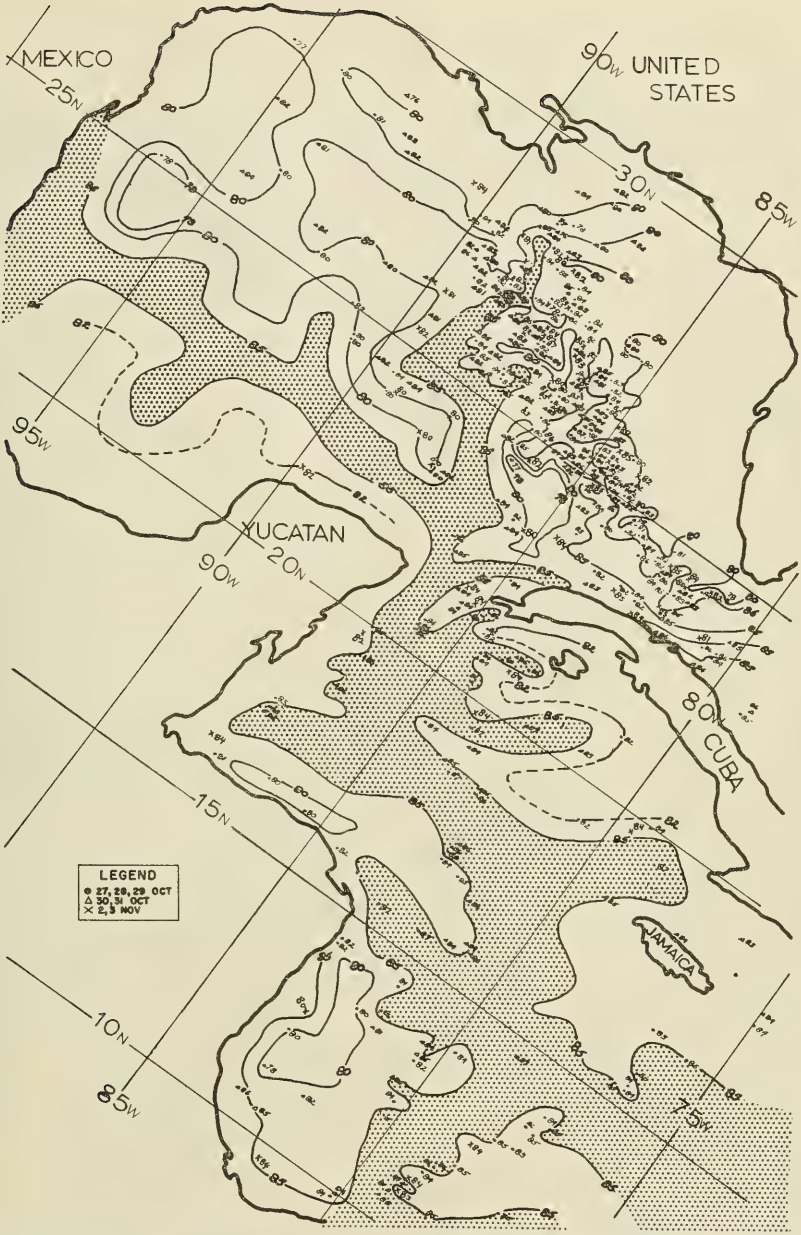


FIGURE 7 COMPOSITE SURFACE TEMPERATURE ANALYSIS FOR THE CARIBBEAN SEA AND GULF OF MEXICO BASED ON FIGURE 6

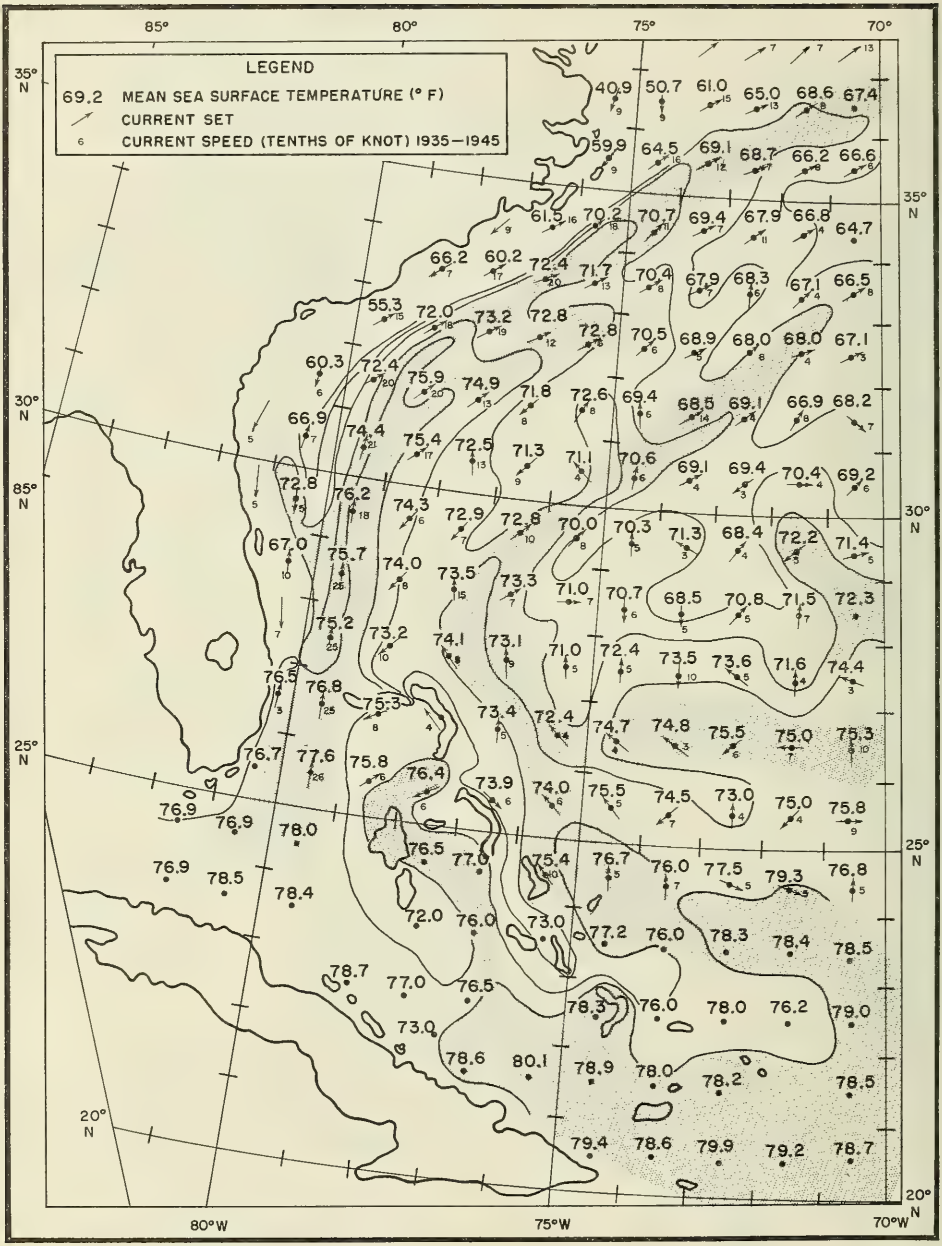


FIGURE 8 MEAN SEA SURFACE TEMPERATURE FEBRUARY 1961 COMPARED TO MEAN CURRENT SPEED FEBRUARY 1935–45

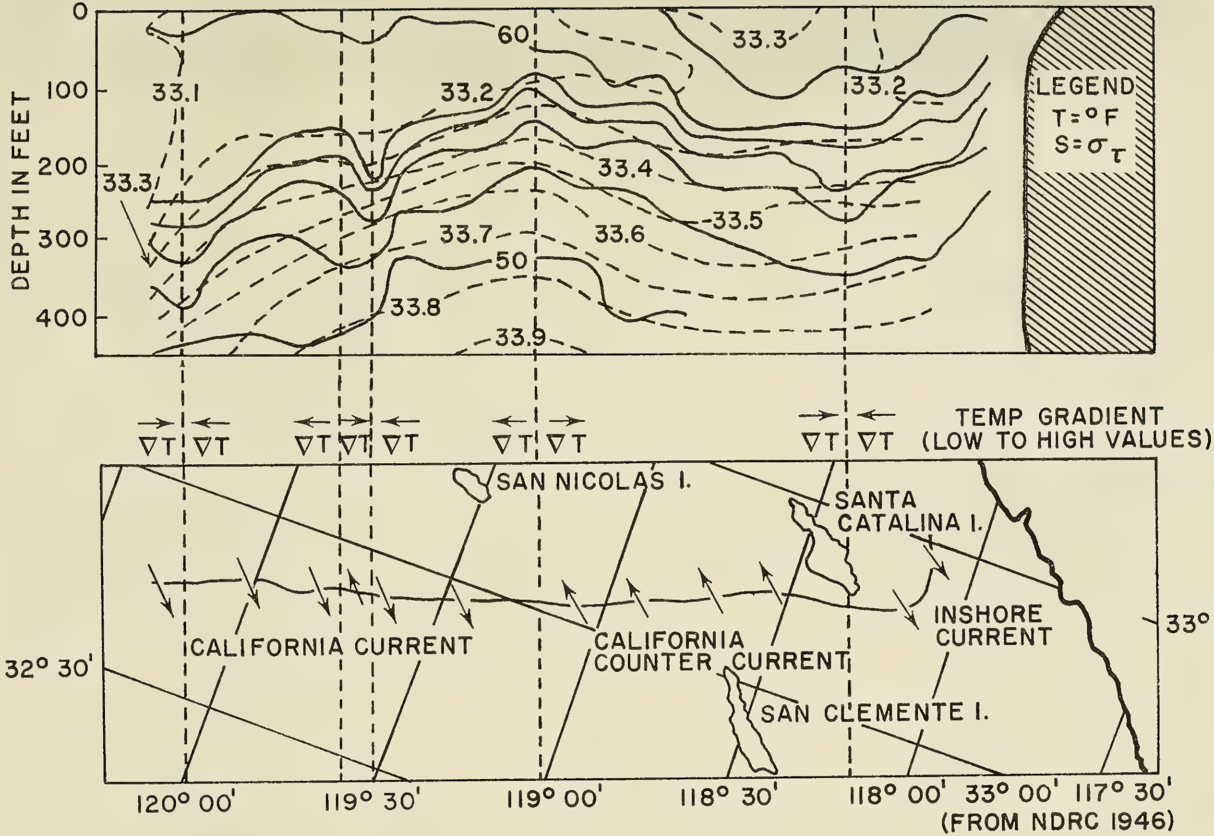


FIGURE 9 TEMPERATURE AND SALINITY PROFILES ACROSS THE CALIFORNIA CURRENTS

V. TEN-DAY COMPOSITE TEMPERATURE CHARTS

Ten-day composite charts should be sufficient for determination of general temperature patterns in areas where the axes of currents are fairly constant. In practice, 10-day composite charts are drawn every 5 days on an overlapping basis. This procedure allows for a relatively large number of reports over small time intervals.

Daily sea surface temperature charts utilize the latest composite chart or daily pattern as a guide. The prime object of composite charts is provision of means for achieving continuity between successive isotherm patterns. In order to conserve space and provide visual data control, the following symbols and color code are used on composite charts.

Ten-Day Composite Chart Data Code

Day	Symbol	Color	Temp. ($^\circ$ F)
1st through 5th . .	•	Purple	<30
6th	-	Light Blue . .	30 - 39
7th	Δ	Green	40 - 49
8th	∇	Black	50 - 59
9th	+	Red	60 - 69
10th	×	Purple	70 - 79
		Blue	80 - 89
		Green	>90

Examples:

55.4° F for the 4th day is coded as •5.4 in black
74° F for the 7th day is coded as $\Delta 4$ in purple

Date indicators serve to show daily variations of water temperatures; the color code minimizes data congestion, aids in scanning large quantities of data, and helps to screen out gross data errors. The last 5 days of data on a 10-day composite chart are carried forward to the next composite chart using dot symbols; the remaining 5 days of data, accumulated from daily charts, are added by using individual symbols as shown in the preceding table. (The last 5 days of data on an 11-20 August composite chart would be transferred to a 16-25 August chart using dot symbols, the remaining days would carry individual symbols.)

Portions of two composite charts for 26 July-5 August and 16-25 August 1961 are shown in Figures 10 and 11. General agreement of the patterns in these charts suggests that oceanic current systems are more stable than

(FOR INTERPRETATION OF SYMBOLS, SEE TABULATION ON PAGE 12.)

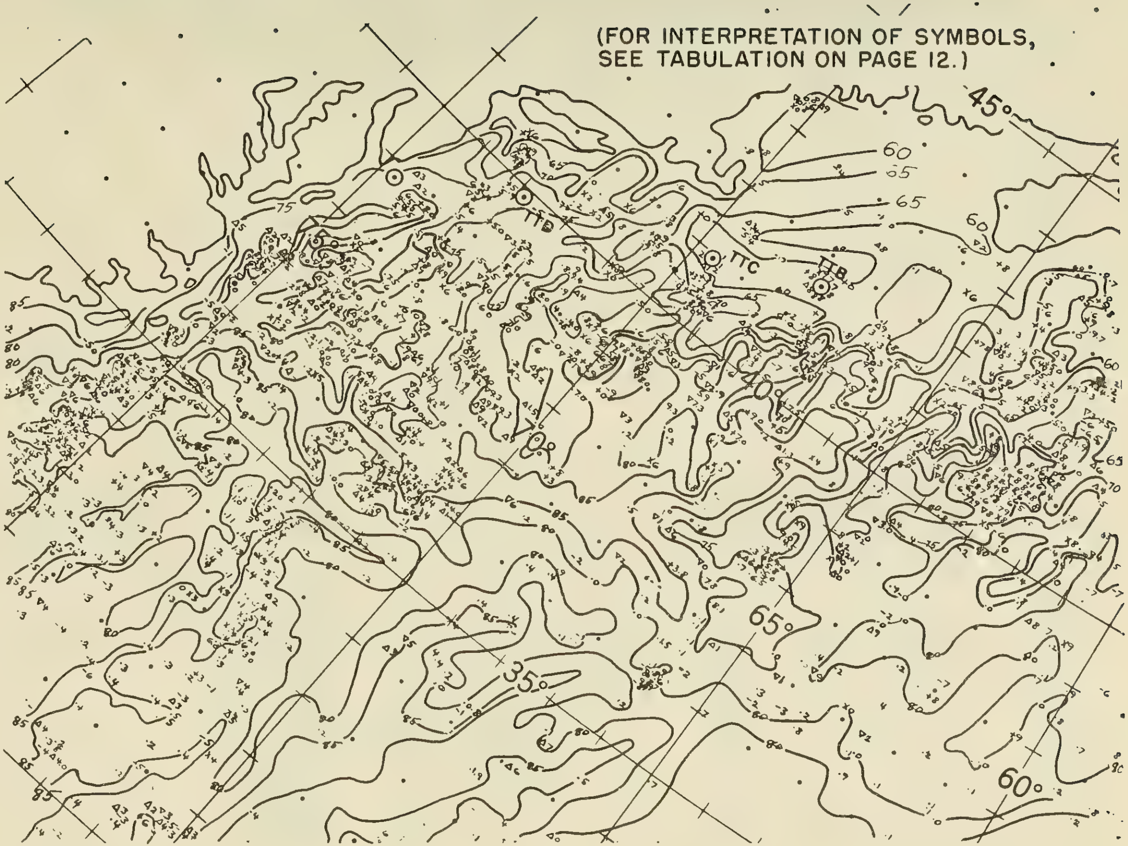


FIGURE 10 COMPOSITE SEA SURFACE TEMPERATURE CHART (° F) 26 JULY—5 AUGUST 1961

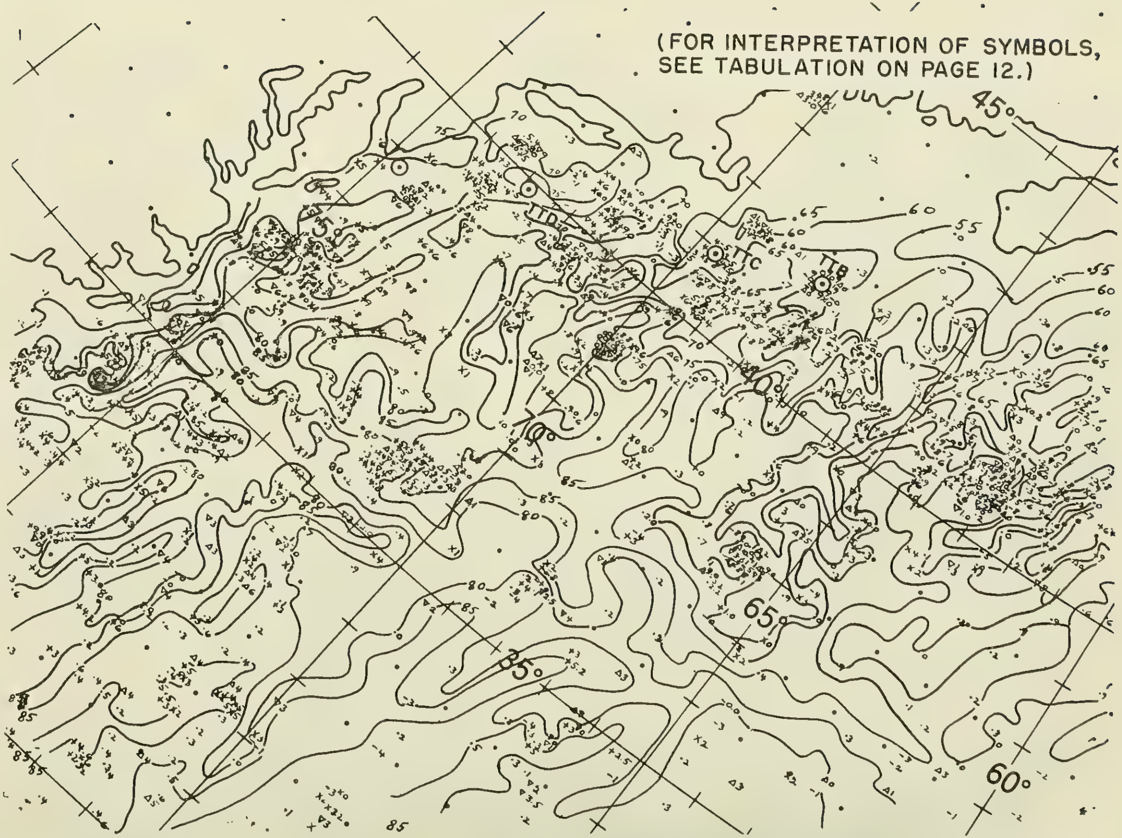


FIGURE 11 COMPOSITE SEA SURFACE TEMPERATURE CHART (°F) 16—25 AUGUST 1961

previously believed. Indeed, many of the variations may be due to data errors. However, the fact that data from a large number of reporting ships form definite patterns indicates that injection temperatures are of operational use.

Figures 10 and 11 show numerous warm and cold water tongues originating from four different current systems (excluding coastal waters). It is noted that a tongue is surrounded by water of approximately the same temperature; whereas a current is flanked by waters of different temperature. The southerly flow of cold water along the eastern edges of warm tongues would result in increased gradients at intervals along the main body of warm water and apparently contributes to the wide distribution of warm and cold waters.

A succession of many charts is usually required to establish a reasonably stable temperature pattern. Winter conditions are most favorable for realization of this end, because temperature contrasts and mixed layers are greatest during this season.

Patterns indicated by composite charts are considered to represent only approximate envelopes of the major current systems responsible for distribution of surface temperature in the sea.

Figure 12 presents an enlarged portion of a composite chart for 16-25 April 1961. The data, plotted in the usual manner, include a relatively large proportion of bathythermograph surface temperatures in whole degrees and tenths (Fahrenheit) which may be compared with injection values. This figure shows the remarkable symmetry of data of both sources over a 10-day period in an area of complex, small-scale current features.

VI. CONCLUSIONS

Although present analytical techniques permit preparation of representative sea surface temperature charts, much improvement is required in the quantity and quality of reports from the synoptic observational net. Continuation of the present analysis program and expansion of the coverage to the entire North Atlantic and North Pacific are planned.

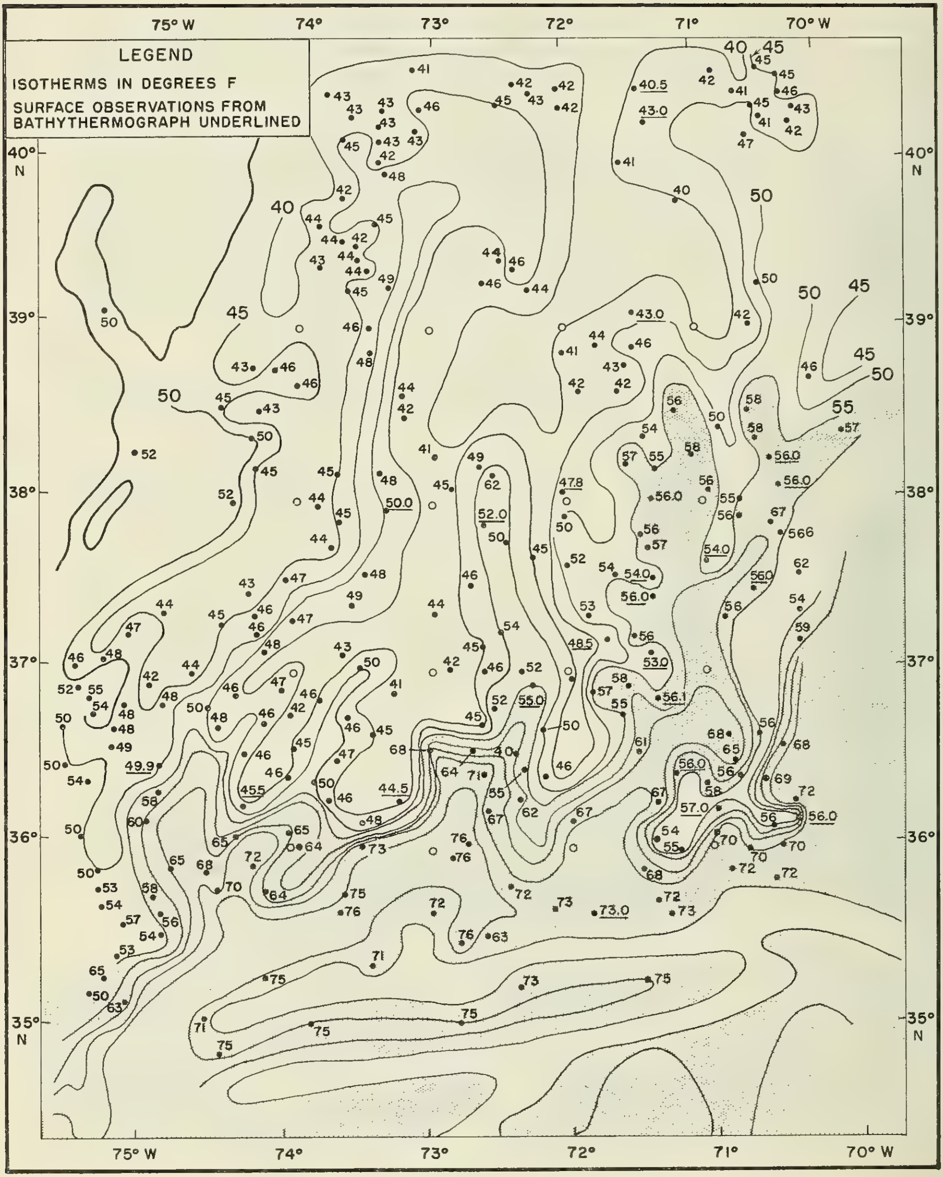


FIGURE 12 COMPOSITE SEA SURFACE TEMPERATURE CHART (° F)
16—25 APRIL 1961

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